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THE EFFECT OF SURFACE IRREGULARITIES ON WING DRAG

IV - MANUFACTURING IRREGULARITIES

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SUMMARY

Tests were made in the N.A.C.A. 8-foot high-speed wind tunnel of a metal-covered, riveted, "service" wing of average workmanship to determine the aerodynamic effects of the manufacturing irregularities incident to shop fabrication. The wing was of 5-foot chord and of N.A.C.A. 23012 section and was tested in the low-lift range at speeds from 90 to 450 miles per hour corresponding to Reynolds Numbers from 4,000,000 to 18,000,000.

At a cruising condition the drag of the service wing was 46 percent higher than the drag of a smooth airfoil, whereas the drag of an accurately constructed airfoil having the same arrangement of 3/32-inch brazier-head rivets and lap joints showed a 29-percent increase. The difference, or 17 percent of the smooth-wing drag, is apparently the drag caused by the manufacturing irregularities: sheet waviness, departures from true profile, and imperfect laps. The service wing, for one condition at least, showed a drag increase due to compressibility at a lower air speed than did the more accurate airfoil.

INTRODUCTION

Tests of an airfoil of 5-foot chord through a wide speed range have been made in the N.A.C.A. 8-foot high-speed wind tunnel to determine the aerodynamic effects of rivets and spot welds (reference 1), simulated lap joints and laps combined with rivets (reference 2), and surface roughness (reference 3).

In order to determine the combined effects of actual laps, rivets, and the manufacturing irregularities incidental to conventional metal-wing construction, tests were

made of a wing of the same specified profile, rivet size and pattern, and lap type and pattern as the one used for the tests reported in references 1, 2, and 3 but constructed according to present-day shop standards. The service wing was furnished by the Bureau of Aeronautics, Navy Department. A comparison of the results for the shop-manufactured wing with those for the more accurately constructed airfoil gives some conception of the aerodynamic effects of the irregularities associated with service construction.

APPARATUS AND METHOD

The tests were made in the N.A.C.A. 8-foot high-speed wind tunnel, which has a closed circular throat. Air flow in the test section is uniform and steady and the turbulence, as measured by sphere tests, is equivalent to that of free air (reference 4). The test wings were mounted (see fig. 1) so as to span the jet completely except for dummy end shields of 10-inch span adjacent to each wall. The active span of the wings was 6 feet. The end shields rotated with the wing for a change of angle of attack but maintained such a clearance that all forces on the active span were transmitted to the balance ring and so to the recording scales.

The shop-fabricated, or service, wing was of 5-foot chord and the specified profile was N.A.C.A. 23012. The arrangement of rivets and laps was as shown in figure 2. The wing was fabricated in the Naval Aircraft Factory at Philadelphia under shop conditions believed to be typical at the present time. Instructions for fabrication of the wing were as follows: "Skin thickness, stiffener arrangement, profile tolerances, workmanship, and finish shall be as nearly as possible representative of conventional practice on service airplanes. No extra precautions to obtain wing surfaces of a quality higher than is common to existing airplanes should be exercised. It is desired that the wing be representative of present-day wing construction."

Careful measurements of the wing indicated that the departure from the true profile was mainly at the nose, as shown in figure 3. The general waviness of the sheet-metal covering is shown by the photograph of figure 4. In addition to these irregularities, the lap joints were observed to be not in contact at all points and some of the

rivets were not perfectly formed. It is probably significant in judging whether the service wing met the requirement of "average" workmanship, as well as indicative of the varying degree of workmanship now required by the industry, to note that, of a large number of manufacturers inspecting the service wing, about as many stated that it was better than their average as stated the opposite.

The more accurate wind-tunnel airfoil was of the same chord and section and departed from the true profile mainly as shown in figure 3. The airfoil was made with a 1/8-inch aluminum covering, painted, sandpapered, polished, and waxed and was known to be aerodynamically smooth; that is, further polishing would have brought about no reduction in drag. Laps were simulated by cutting spanwise grooves, of the proper profile, in the covering.

The wings were tested at three angles of attack corresponding to lift coefficients of 0, 0.15, and 0.3 at air speeds from 90 miles per hour to the speed that gave a wing loading of 50 pounds per square foot or to the speed corresponding to the compressibility burble, whichever was lower. The method of reducing data, and the reasons for presenting the increase in drag coefficient rather than the absolute drag coefficients are discussed in reference 1.

PRECISION

An analysis of the probable errors in the present series of tests indicates that the increases in drag coefficients are accurate to within ±0.0001, corresponding to ±1.4 percent of the drag of the smooth airfoil, except at speeds below 100 and above 400 miles per hour where the errors may be twice this magnitude.

RESULTS

The results of tests of the two wings are shown in figure 5 for three lift coefficients. The increase in drag coefficient C_D is the amount by which the drag coefficient for any condition exceeded the drag coefficient of the smooth wing at the same speed. As an aid in visualizing the magnitude of the increases, values are spotted on the curves to show the increase as a percentage of the drag of a smooth N.A.C.A. 23012 airfoil as extrapolated from full-scale wind-tunnel results. The air speeds

noted are not the actual test velocities but are speeds that at sea level under standard atmospheric conditions would produce values of Mach number M, (ratio of air speed to speed of sound in the air) equal to the test values. The Reynolds Numbers are the averages of the actual Reynolds Numbers for the various test runs. None of the Reynolds Numbers departs enough from these averages to affect the results appreciably. Additional data from reference 2 are included to show the magnitude of the effects caused by rivets and laps, alone and in combination.

DISCUSSION

The curves of figure 5 show that the drag of the shop-fabricated service wing was consistently greater than that of the more accurate wing with the same rivets and laps by 13 to 17 percent of the smooth-wing drag. There appears to be no marked scale effect on the drag increment caused by the manufacturing irregularities.

In the specifications for the construction of the service wing, it was necessary to permit the fabricator to choose a sheet thickness that would be most nearly conventional in order that the resulting workmanship, sheet waviness, etc., should be entirely normal. The fact that 0.032-inch sheet was chosen prevents an exact comparison with the wind-tunnel model, simulating 0.018-inch sheet, on account of the resulting different lap height. The results of reference 5 indicate that, for laps alone, the difference in drag coefficient due to the different lap height would be of the order of 0.0003. The actual difference, however, was probably of the order of the experimental error because, as discussed in the next paragraph, the drag of lapped joints is diminished by the presence of rivets. In view of the magnitude of the drag increases due to other causes, the effect of the difference in lap height may be considered negligible.

The present tests investigated the effect of manufacturing irregularities in the presence of rivets and laps. It is generally considered that aerodynamic effects, such as these, are not additive; the results from previous tests that are shown for rivets alone, laps alone, and rivets and laps combined bear out this contention in that the sum of the effects of the two items is greater than the effect of the two items combined. Considered thus,

the effect of manufacturing irregularities probably is conservative, as measured in the presence of rivets and laps, and the same irregularities (sheet waviness and departures from true profile) may be even more important on a wing that is otherwise smooth.

The drag curve for the service wing at zero lift is interesting as it rises quite rapidly in the region of 400 miles an hour. It is believed that a compressibility burble was precipitated by the bulge in the lower portion of the nose at lower speeds than would be normally predicted for the true section because this bulge was in a critical region for the attitude of zero lift.

The over-all drag increases that are shown for the service wing give a true picture of the detrimental effect of the combination of rivets, laps, and manufacturing irregularities that obtained on the service wing; the results are applicable to wings of other sizes if the scale of all irregularities remains the same with respect to the wing chord. As pointed out in reference 1, care must be exercised in applying the results if the rivet size and sheet thickness do not vary directly with the chord. Probably the same precautions must be taken in applying the results for manufacturing irregularities but definite information must come from a more complete and systematic study of manufacturing irregularities.

CONCLUSIONS

1. The drag of a shop-manufactured wing of average workmanship, with rivets and lap joints, was found to be as much as 46 percent greater than the drag of a smooth wing of the same profile.

2. The drag of a shop-manufactured wing was greater than the drag of a more accurate wing with the same arrangement of rivets and laps, by 17 percent of the smooth-wing drag.

3. Manufacturing irregularities produced a premature increase in drag due to compressibility effects.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 7, 1937.

REFERENCES

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4. Robinson, Russell G.: Sphere Tests in the N.A.C.A. 8-Foot High-Speed Tunnel. Jour. Aero. Sci., vol. 4, no. 5, March 1937, pp. 199-201.

5. Hooker, Ray W.: The Aerodynamic Characteristics of Airfoils as Affected by Surface Roughness. T.N. No. 457, N.A.C.A., 1933.

FIGURE LEGENDS

Figure 1.- Service wing of 5-foot chord mounted in the wind tunnel. The wing is set at a large negative angle to show the upper surfaces.

Figure 2.- Positions of laps and rows of rivets for both wings used in the tests.

Figure 3.- Comparison of profiles of wind-tunnel model and service wing with true N.A.C.A. 23012 profile.

Figure 4.- Arrangement to show the degree of sheet waviness of service wing.

Figure 5.- Increase in drag of service wing, and of wind-tunnel model with laps and rivets, over drag of smooth model. Chord, 5 ft.; section, N.A.C.A. 23012.

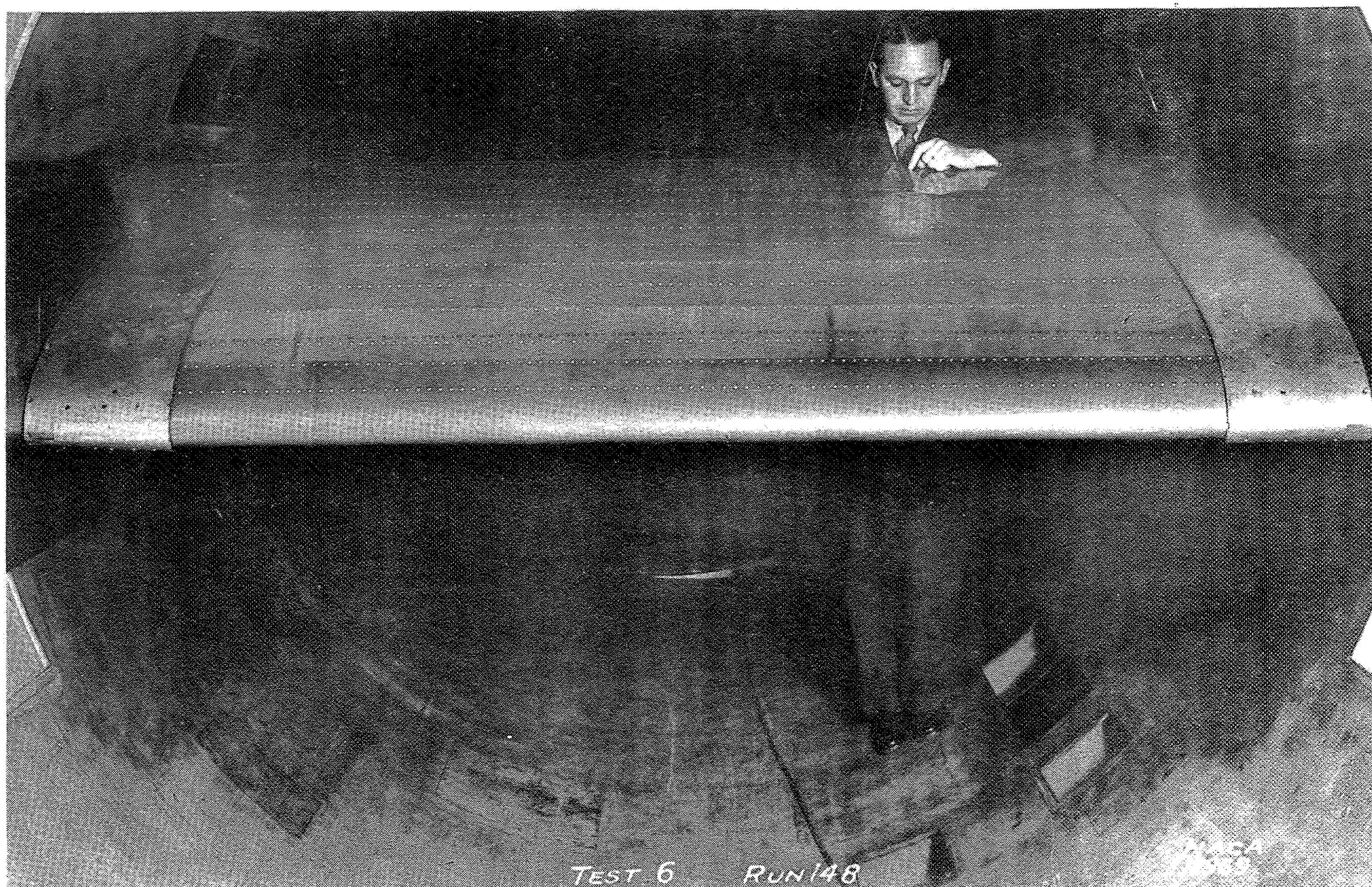


Figure 1.- Service wing of 5-foot chord mounted in the wind tunnel. The wing is set at a large negative angle to show the upper surface.

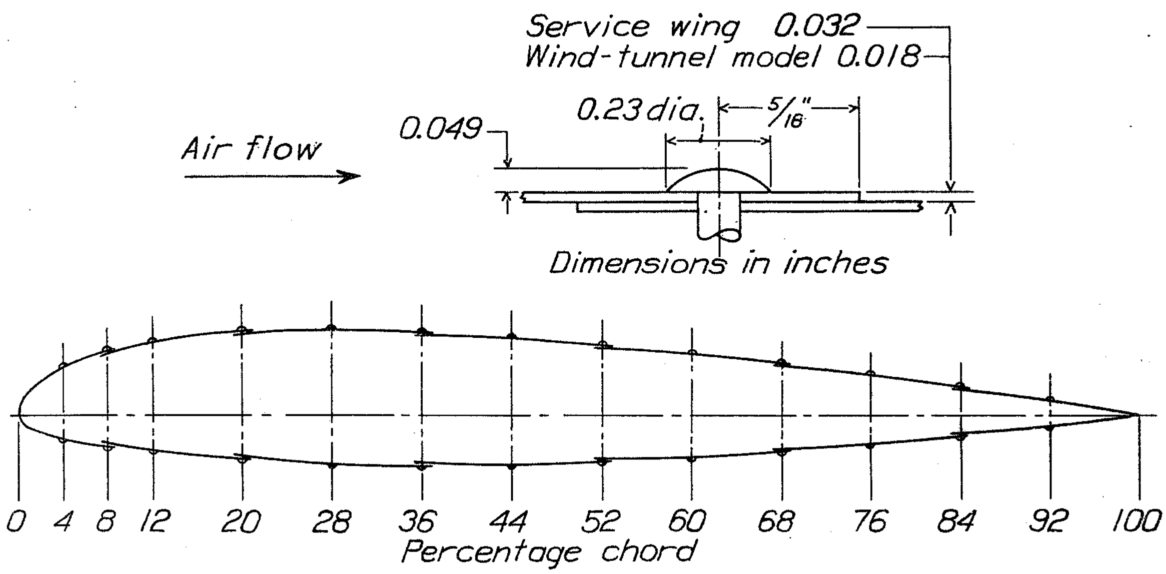


Figure 2

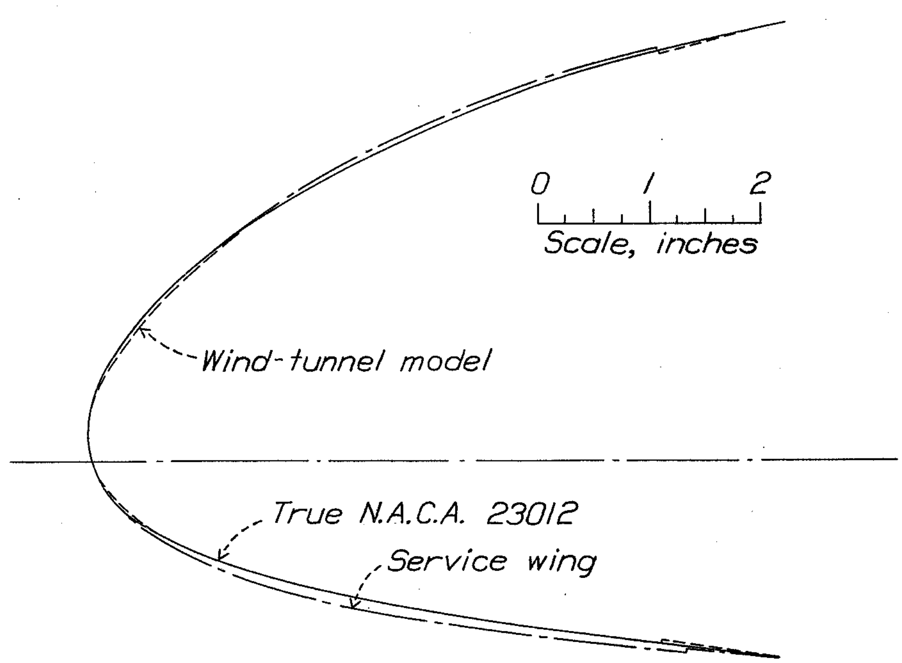


Figure 3

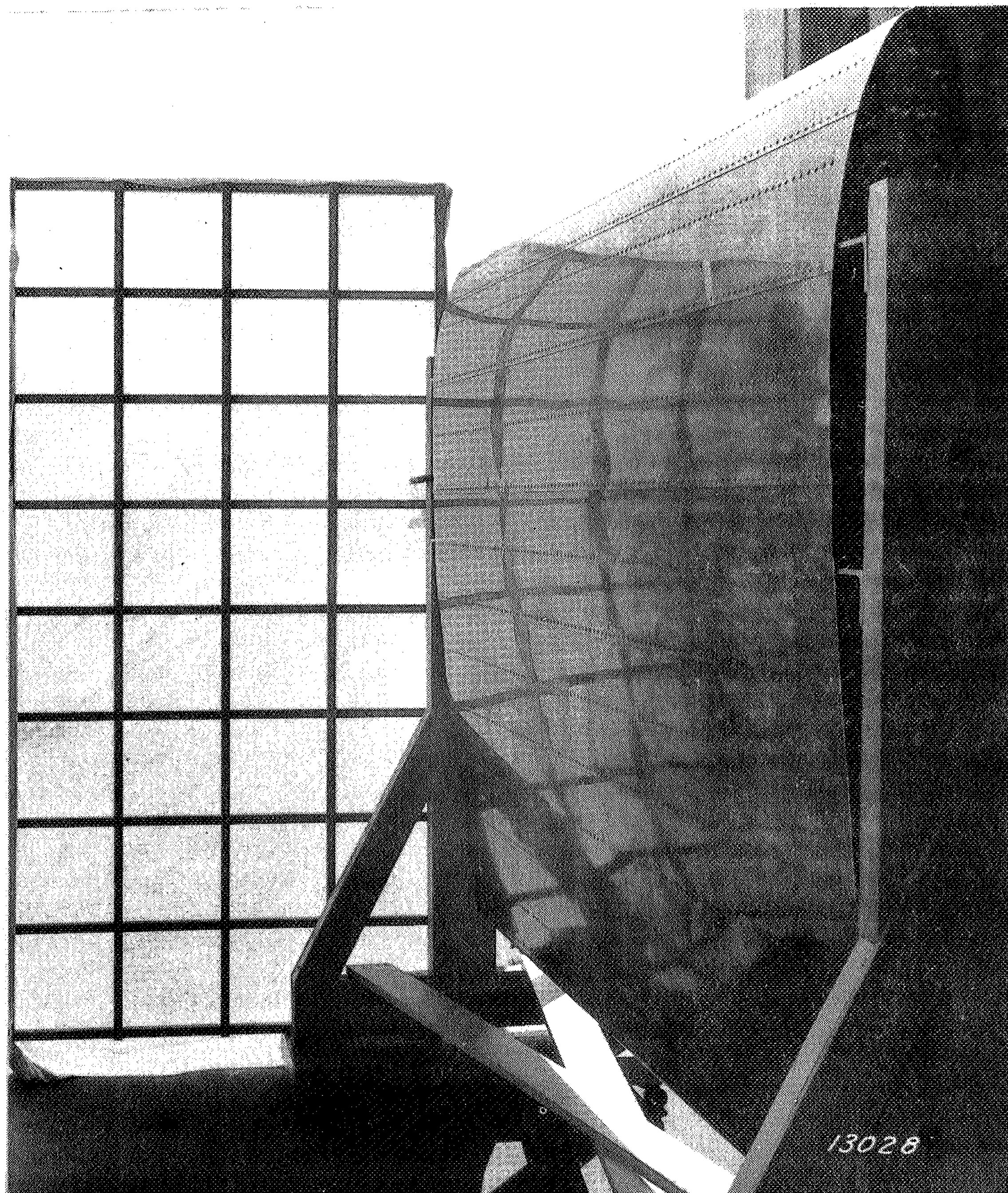
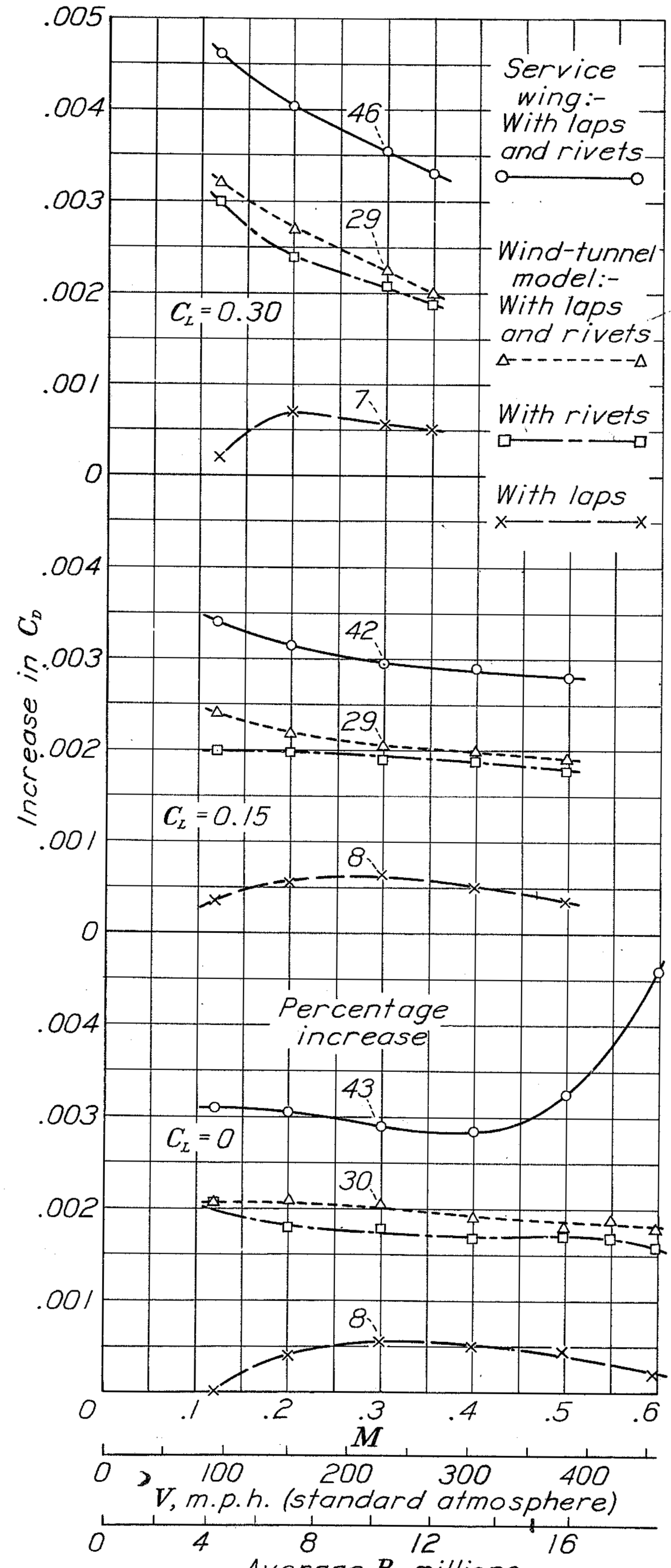


Figure 4.- Arrangement to show the degree of sheet waviness of service wing.



.005
.004
.003
.002
.001
0
.004
.003
.002
.001
0
.004
.003
.002
.001
0
Increase in C_D
Service wing:-
With laps and rivets
Wind-tunnel model:-
With laps and rivets
With rivets
With laps
C_L = 0.30
C_L = 0.15
C_L = 0
46
29
7
42
29
8
43
30
8
Percentage increase
.1
.2
.3
.4
.5
.6
M
100
200
300
400
V, m.p.h. (standard atmosphere)
4
8
12
16
Average R, millions

Figure 5